AN INTRODUCTION TO RADIO ASTRONOMY

Yerkes Observatory photograph

Get into this fascinating new hobby with a simple homebrew telescope system.

BY DAVID HEISERMAN

RADIO astronomy has changed our understanding of the universe. Behind this new science is an electronic, rather than an optical "eye," called the *radio telescope*. It was the radio telescope that first brought to our attention the existence of quasars, pulsars, and galaxies that seem to disappear at the very brink of space and time.

Shortly after World War II, radio astronomy became a serious science. The wartime effort brought tremendous advances in communication and radar receivers and antennas that had the bandwidths, low noise levels, and high gain characteristics required for radio astronomy. Professional astronomers seized the opportunity to explore the universe by studying the radio signatures of planets, stars, and galaxies. The amateur astronomer, however, has shown uncharacteristic shyness toward radio astronomy.

Part of the amateur's reluctance to get involved in radio astronomy has been the lack of budget-priced "viewing" equipment. Though this may have been an obstacle in the past, vhf and uhf equipment and devices are now readily available for amateur use.

In this article, we will discuss radio astronomy in general terms to introduce amateur optical astronomers and non-astronomers to this fascinating and relatively new hobby. We will discuss what a radio telescope is and how to listen to the cosmos with a simple homemade telescope.

Tuning In the Stars. The stars that fill the nighttime skies with their twinkling blue-white light visible to the human eye emit electromagnetic energy in the visible spectrum. It is to these that the optical astronomer aims his telescope. Many large objects in space also emit electromagnetic energy at longer wavelengths, in the shf, uhf, and even vhf portions of the radio spectrum. Obviously, no optical telescope allows the human eye to view these wave-lengths. For these, you need a radio telescope.

The real impact of radio astronomy has not come from matching up light and radio waves from visible stars. Most of the stars visible to the human eye generate relatively low amounts of energy in the radio spectrum. In contrast, the most powerful radio sources outside our solar system include distant galaxies, dense star clusters, and remnants of exploded star systems.

Consequently, a simple backyard radio telescope can (and does) readily respond to colliding galaxies on "the other side of the universe," though it cannot detect radiation from well-known stars like Vega and Sirius. Furthermore, a simple radio telescope can pick up radiation from sources that are optically obscured by clouds of gas and dust, a condition that exists when an optical telescope is turned toward the center of the Milky Way galaxy. Also, radio telescopes can "see" through clouds, air pollution, and high ambient light at night and can be used for daylight "viewing."

The universe is literally alive with white-noise radio "static." Every hot object—which includes stars, galaxies, etc.—emits broadband radio energy that has an intensity roughly proportional to its temperature. As illustrated in Fig. 1, this kind of *thermal* radiation rises in intensity through the vhf and uhf parts of the radio spec-

Figures 1, 2, and 3 are from the author's book "Radio Astronomy for the Amateur," published by Tab Books, Blue Ridge Summit, PA.

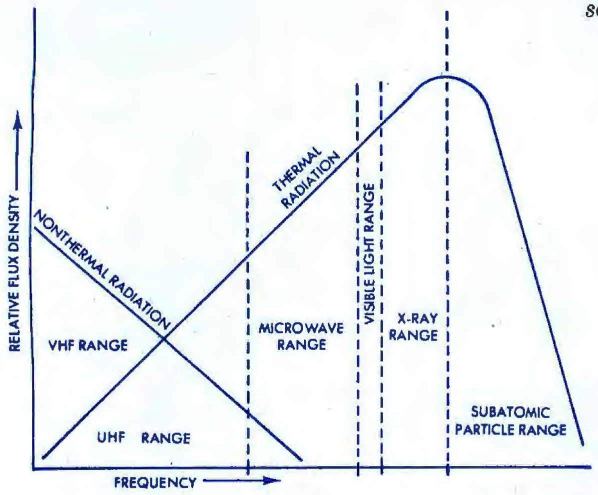


Fig. 1. Relative intensity of thermal and nonthermal sources across the spectrum.

trum. It reaches a peak just beyond the visible wavelengths.

There are also nonthermal sources of radio noise in space. Most such sources are created by high-velocity electrons whipping through intense magnetic and gravitational fields that surround most stars and galaxies. Note from Fig. 1 that the intensity of nonthermal radiation is highest at the low end of the vhf radio band.

Many radio sources in space generate noise that is both thermal and nonthermal. The significance of this is that an amateur astronomer has the option of observing the sources anywhere across the radio spectrum. Some sources, however, tend to generate larger doses of radio energy at one end or the other of the spectrum. The sun and Jupiter are classic examples of predominantly nonthermal sources of radio energy.

The sun is our most powerful radio source. While it generates much high-frequency thermal radiation, intense nonthermal signals from sunspots and solar flares make it an excellent subject for the novice radio astronomer. The planet Jupiter is the next strongest radio source. Since it is rather cold, its thermal radiation is negligible (as far as amateurs are concerned). Jupiter's powerful gravitational field, however, sweeps gigantic swarms of electrons through the planet's upper atmosphere, creating noise that can be heard easily on a radio telescope (as low as 21 MHz).

There is a third class of radiation, known as the 21-cm hydrogen line, that is of special interest to radio astronomers. Hydrogen atoms make up an overwhelming majority of all the matter in the universe. They radiate a "resonant" energy at a constant frequency of 1.428 GHz. Anywhere there is hydrogen, this radiation is present. Hence, professional radio astronomers have keyed most of their research to the 21-cm band. Unfortunately for amateurs, 21-cm equipment with the proper specifications is either too elaborate or too expensive—or both—for the average amateur's budget. Until microwave equipment becomes available with more suitable specifications at a lower cost, there is little an amateur radio astronomer can contribute at 21 cm. Even so, there is a lot for the amateur astronomer to see at the lower vhf and uhf frequencies.

The most fruitful working range for amateur radio astronomers is in the vhf and uhf bands where nonthermal and thermal sources have about the same energy levels. The technology is fairly well established in this range, and few professional radio astronomers have done work here.

The Radio Telescope. From a block-diagram point of view, a radio telescope is little more than a directional antenna, wideband receiver, and some type of recording/readout device. Adding a device for aiming the antenna and calibrating the receiver complete the picture.

Whenever a radio source in space enters the antenna's beam pattern, the readout device registers a gradual increase in noise signal level. The signal in most cases is pure white-noise static. As the source passes through the center of the beam, the readout device will show a peak noise level. Then, the noise level drops off as the object moves away from the antenna. The

TABLE 1—ANTENNA AND MOUNTING CHARACTERISTICS

	Advantages	Disadvantages
Antenna:		
Multi-element beam (YAGI)	Moderate to high gain; relatively simple construction; many impedance-matching options	Narrow bandwidth; polarized in one plane
Beam array	High gain; any linear polarization possible; many impedance-matching options	Mechanically awkward; requires great deal of working space
Single helix	Inherently wideband; circular polarization; moderate gain; responds to circular or any plane polarization	Mechanically awkward in vhf range; polarized in one "sense" (left- or right-handed).
Helical array	Inherently wideband; high gain; responds to linearly or circularly polarized signals	Mechanically awkward in vhf range; "sense" conscious.
Parabolic reflector	Extremely directional; high gain	Very difficult to build
Mounting:		
Fixed	Simple construction	Not steerable in any plane
Altitude	Relatively simple construction	Azimuth is fixed
Altazimuth	Fully steerable	Relatively complicated construction; awkward in lower vhf range; works in horizon coordinates
Equatorial	Fully steerable; work in celestial coordinates	Complicated construction

TABLE 2—RECEIVER CHARACTERISTICS

Receiver Type	Advantages	Disadvantages
Shortwave communications	High gain; suitable converters and preamplifiers available	Narrow bandwidth
Commercial FM	Good gain; wideband; low noise	Restricted to 88-108-MHz
Custom-designed homemade	High gain; wide bandwidth; low noise	Requires know-how to build and align
TV tuner	Readily available; wide bandwidth	Low gain; poor noise figures

stronger the radio source, the higher the peak signal response.

Anyone familiar with communication systems will find the purpose of each element in a radio telescope system rather obvious, but a brief summary is in order. The antenna picks up radio signals from remote sources. The antenna mounting steers the antenna to the point in the skies from which the signal originates. The receiver then tunes, amplifies, and detects the signal. Finally, the recording system displays or records the results. The special requirements imposed on these common system components, however, require further discussion.

The antenna, for example, must have a higher power gain than is normally required for communication purposes, and it must be highly directive. Only antennas with gain figures in excess of 10 dB are worth considering for serious radio astronomy work. The major lobe should have a width of no greater than 30° between the half-power points. By the same token, the bandwidth of the antenna should be 2 MHz or more.

Although parabolic antennas seem to be the hallmark of professional radio astronomy, they are not the best choice for amateur astronomers, especially newcomers. Considering both practical and theoretical features, a tuned multi-element beam antenna is the best all-around choice for a vhf radio telescope system, while a quad helix array performs better in the uhf range. Table 1 summarizes the advantages and disadvantages of antenna systems in the light of amateur radio astronomy.

Most amateur radio astronomers find that they spend considerable time and effort designing, building, and debugging the antenna and antenna mounting system. While receivers and recording devices with the necessary specifications are available commercially, the antennas are not. The ultimate success or failure of a radio astronomy system rests heavily on the quality and proper selection of an antenna system, making the extra time and effort very worthwhile.

As far as the receiver is concerned, it must have high gain, low noise, good stability, and wide bandwidth. These particular requirements are almost self-contradictory, and run-of-the-mill radio construction projects seldom meet them. Fortunately, there are some ready-made systems that can do the job.

Any wideband radio receiver that has a sensitivity of 5 μV or better is suitable for amateur radio astronomy work. Shortwave communication receivers can be used, provided they have a sensitivity on the order of 0.5 μV to make up for their narrow predetection bandwidth. Commercial FM receivers work rather well in a vhf radio telescope system because most of them have good sensitivity figures and a wide predetection bandwidth. (Incidentally, there is no need to disable the FM detector or limiter stage to get satisfactory results from an FM receiver. The receiver passes wideband noise whenever there is no carrier present.)

It is tempting to try using a uhf TV receiver to work the uhf end of the radio astronomy spectrum. However, while TV receivers have the required bandwidth, they have intolerably low sensitivity figures. The wideband characteristic never quite makes up for the poor sensitivity, and any attempt to use a TV receiver is bound to produce disappointing results. Table 2 compares the various types of receivers available.

The data readout or recording device, the final stage in the system, can be as simple as a voltmeter or as complex and expensive as a chart recorder. In any case, it must provide information with reasonable precision and reliability. Table 3 lists the relative advantages and disadvantages of three types of recording devices.

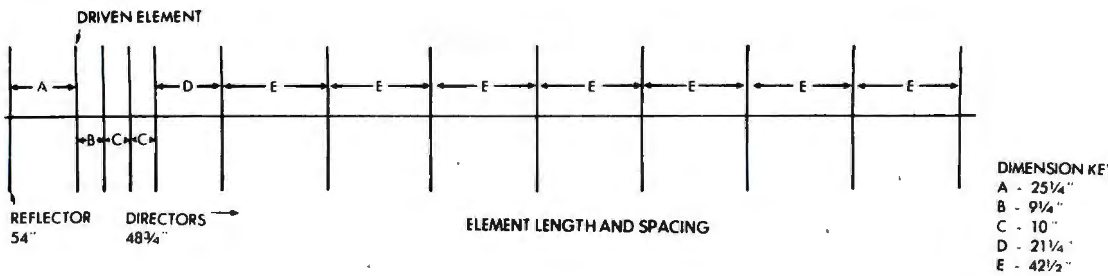
Few amateur radio astronomers can resist the temptation of listening to the hissing signals from the cosmos through a loudspeaker. With the notable exception of signals from Jupiter, radio signals from space are not very exciting to hear. A loudspeaker is nevertheless a popular kind of auxiliary "readout" device for amateur radiotelescopes.

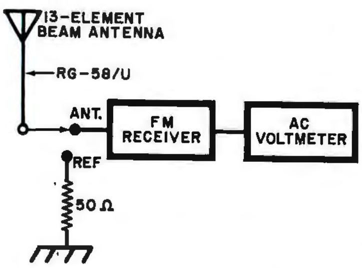
The basic specifications for simple radio telescopes are summarized in Table 4.

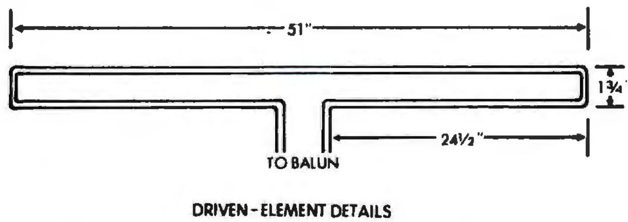
Getting Started. Doing anything really useful with a radio telescope requires at least a nodding acquaintance with basic astronomy. A radio astronomer must be able to aim his antenna at a particular target or know what sources are passing through the

TABLE 3—RECORD/READOUT DEVICE CHARACTERISTICS

Monitor Device	Advantages	Disadvantages
Voltmeter	Readily available	Requires constant attention during recording sessions
Chart recorder	Requires little or no attention during recording sessions; provides permanent record of raw data	Initially expensive
Tape recorder	Requires little or no attention during recording sessions; provides permanent record of raw data; can be used for other purposes	Data must be transcribed







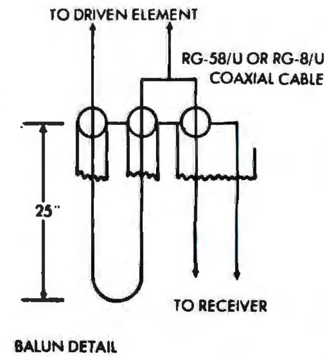


Fig. 2. Block diagram (left) and details for a 13-element beam antenna (above) for a 110-MHz radio telescope described in text.

lobe pattern of his antenna at a given time. So, he must be able to read star maps and interpret prediction tables. However, an experimenter doesn't have to be familiar with astronomy to set up a simple telescope and get it working.

The 110-MHz radio telescope system illustrated in Fig. 2 can be assembled for about $30, assuming you already have an FM receiver and a voltmeter. A beginner can assemble this system, use it to spot a couple of radio sources, and finally determine for himself whether or not he wants to learn more about astronomy and build another system suitable for more extensive projects.

Although most of the time and money involved in this 110-MHz system goes into building the antenna and its mounting, there is really nothing unusual about it. It is a standard 13-element yagi array cut for a center frequency of 110 MHz. The elements can be made from heavy aluminum wire and mounted on a boom made up of 8′ (2.5-m) long sections of 1½" (3.8-cm) diameter aluminum tubing. Mount the boom assembly on a standard 2" (5.1-cm) diameter steel mast to raise the balance point of the boom about 16′ (5 m) above ground level. Experimenters who are uncertain about construction techniques for this type of antenna should look up further details in *Radio Astronomy for the Amateur* by this author (TAB Books, Blue Ridge Summit, PA 17214). This book also contains all the information you'll need to get seriously into radio astronomy on an amateur level. Alternatively, you can consult a recent edition of *The ARRL Antenna Book* for antenna construction tips.

Fix the antenna mounting so that it always aims the boom due south. The boom must be mounted so that it can be adjusted in altitude (pivot up and down). Use a length of RG-58/U coaxial cable to carry the antenna signal to the input of a moderately good FM receiver. An impedance-matching transformer can be used to match the 50-ohm impedance of the antenna/cable to the 300-ohm impedance of the antenna input circuit on most FM receivers. (The matching transformer isn't absolutely necessary for trial runs.) Then, connect a voltmeter that has a 1- or 1.5-volt ac range across the receiver's speaker output terminals. The meter will now register the system's output noise level.

A switch at the antenna input on the receiver can be used to replace the antenna with an equivalent-value load resistor. Since the resistor generates a negligible amount of noise, any noise detected by the voltmeter while the resistor is in the circuit represents the receiver's inherent noise level. Switching the antenna back into the system will always cause a rise in the noise level. The increase in noise level represents the signal level present at the antenna.

The sun is usually the best subject for trying out a new radio telescope, mainly because it is so easy to find and is such a powerful radio source. To check out this simple system, adjust the altitude of the antenna so that it points directly at the sun when it crosses the celestial meridian (an imaginary line that runs from directly overhead down to the southern horizon). Make this initial adjustment about two hours before the crossing is to occur.

All readings described here were taken with the receiver tuned to 110 MHz, as determined with the aid of an r-f signal generator. The treble control on the receiver was set to maximum and the afc switch to off. The volume control must be set for full audio gain while taking readings, but it can be turned down at other times if the hiss-

TABLE 4—BASIC SPECIFICATIONS FOR SIMPLE RADIO TELESCOPE

Parameter	Minimum	Nominal	Excellent
Antenna gain	10 dB	15 dB	20 dB
Receiver sensitivity	5 μV	1 μV	0.5 μV
Receiver bandwidth	100 kHz	2 MHz	6 MHz

Note: *Minimum* is capable of detecting signals from sun, Jupiter, Cassiopeia A and galactic plane; *nominal* and *excellent* are capable of working at least five sources outside solar system.

ing sound becomes a nuisance.

Switch to the resistor and note the voltmeter reading. If possible, use the meter's zero-adjust control to set the meter pointer to zero. If this isn't possible, set the pointer for the lowest possible reading and note it on a sheet of paper. Now, switch to the antenna and note the new reading. Subtract the previous (reference) reading from the new reading to obtain a fairly good estimate of the background noise being picked up by the radio telescope.

Take both readings in a similar fashion at 30-minute intervals over a period of four hours or so. Always note the time and difference between readings. When the experiment is completed, the data should show a distinct rise in the noise levels as the sun passes through the beam pattern.

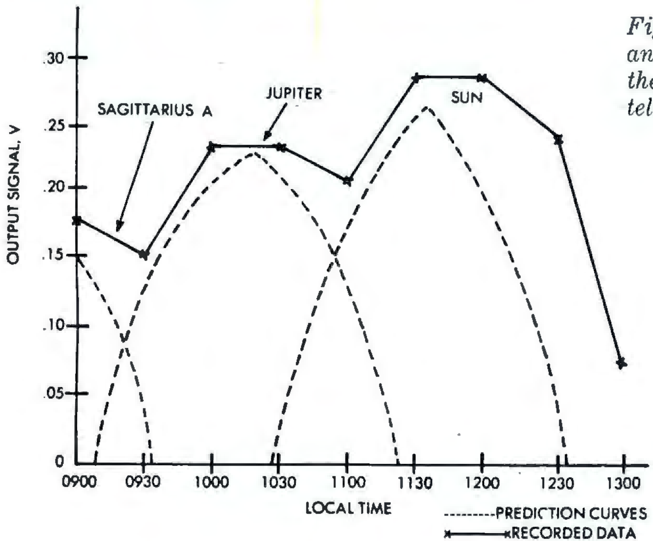


Fig. 3. Results of an experiment with the 110-MHz radio telescope system.

Illustrated in Fig. 3 are the results of a four-hour recording session identical to that described above. The plotted data (solid lines) show signals arriving from three different sources: Sagittarius A, Jupiter, and the sun. Sagittarius A, a powerful radio source representing the center of our galaxy, was just moving away from the antenna when the session began. Jupiter then moved into the beam, followed by the sun. Three powerful radio sources are not always lined up in this way, so an experimenter shouldn't be disappointed if his data shows only a single response representing the sun.

Our simple 110-MHz system is capable of detecting signals from at least seven different radio sources of extraterrestrial origin. These include: the sun, Jupiter, Sagittarius A, Cassiopeia A, Taurus A, and Virgo A. Electronics experimenters who are unfamiliar with the locations of the constellations listed here can seek the aid of an experienced amateur astronomer.

Our simple radio-astronomy system has a secondary application as a bonus. It makes an excellent system for FM DX'ing. ◈